AIRPLANE FLIGHT CONTROLS

FULFILLS PA.I.G, CA.I.G, AI.II.E

Objective	
The student shall understand the methods for controlling aircraft on the ground and in flight. The student shall become familiar with various aircraft configurations to relate theory discussed in airplane performance with physical implementations of controls.	
Instructor Actions	**Student Actions**
- Explain and present images of the individual flight controls - Explain methods of control actuation - Walk the student around an airplane and demonstrate control actuation - Demonstrate effects of control lubrication	- Take notes and participate in instructor's discussion - Identify flight control system and explain its operation on training aircraft (Piper Tomahawk)
Case Studies	**Equipment**
- Improperly Rigged Controls	- Model Airplane - Pilot's Operating Handbook - Training Airplane
Completion Standards	
The student shall explain how movements of controls actuate the control surfaces and the advantages or disadvantages of flight control types implemented by a particular aircraft's manufacturer.	

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ELEMENTS

RESOURCES

FAA-S-ACS-6C Private Pilot ACS - Area I Task G
FAA-S-ACS-7B Commercial Pilot ACS - Area I Task G
FAA-S-ACS-25 CFI ACS - Area II Task E

FAA-H-8083-2 Risk Management Handbook
FAA-H-8083-3C Airplane Flying Handbook
FAA-H-8083-25C PHAK Chapter 6: Flight Controls

Piper Tomahawk POH

1. AIRPLANE AXES

Axes - use body. Use training aid

Attitude control is the single most important consideration of vehicle design. Cars use simple wheel steering to turn, spacecraft utilize momentum exchange devices and thrusters to slew, and airplanes use ailerons, elevators, and rudders, sometimes combined into single surfaces, to orient around its axes. In our 3D world, airplanes need adequate control around three axis: the longitudinal, lateral, and vertical axes. The longitudinal axis runs lengthwise (nose to tail), the lateral axis runs side-to-side (wingtip to wingtip), and the vertical axis runs vertically (floor to ceiling). Of course, all axes pass through the aircrafts center of gravity as seen in Figure 1. To reach a desired aircraft attitude, we perform a series of rotations about these axes, usually simultaneously. Rotations are usually coupled, meaning a rotation about one axis induces a rotation about another. As a result, multiple inputs are required for smooth and proper control. Rotations about these axis are accomplished using the primary flight controls.

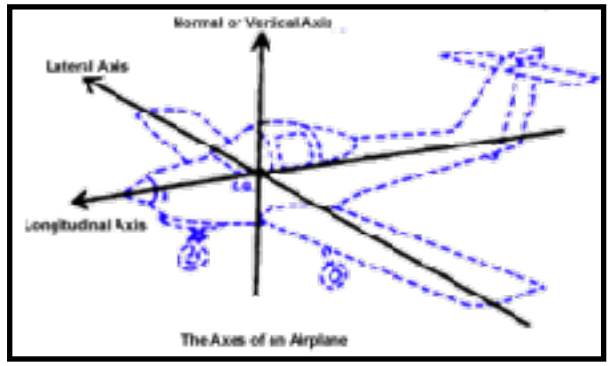


Figure 1 Airplane Axes

2. PRIMARY FLIGHT CONTROLS

2.1. Ailerons

Give SBT example - traffic pattern Horiz comp of lift

Ailerons control rotation about the longitudinal axis. On the outboard trailing edge of each wing, they move in opposite directions to induce a roll. The downward moving aileron increases the effective camber of the wing which increases lift (as discussed in principles of flight). The upward moving aileron spoils airflow over the wing and decreases the camber (sometimes to negative camber), decreasing lift. This lift imbalance results in a roll. However, the aileron producing more lift is subject to the increased drag resulting from the production of lift, known as induced drag. As such, aileron movement will couple with a rotation about the vertical axis and introduce “adverse yaw”. This is simply corrected with rudder application.

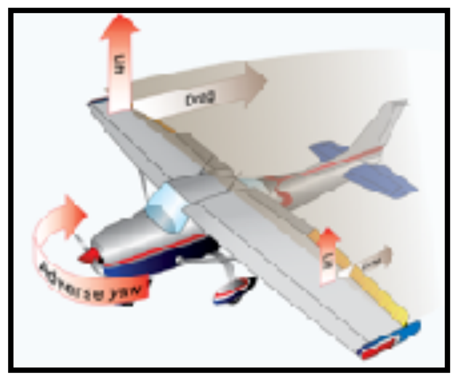


Figure 2 Adverse Yaw

Methods have been developed to minimize the adverse yaw, including differential ailerons and frise-type ailerons. For differential ailerons, the raised aileron is raised more than the other aileron is lowered, increasing drag on the lowered wing to decrease adverse yaw effects.

To turn the aircraft, the yoke is rotated to achieve the desired bank angle. Then, the yoke is returned to neutral with only minor inputs needed to account for the overbanking tendency or disturbances. When the desired attitude is reached, opposite aileron is input to return the aircraft to wings level.

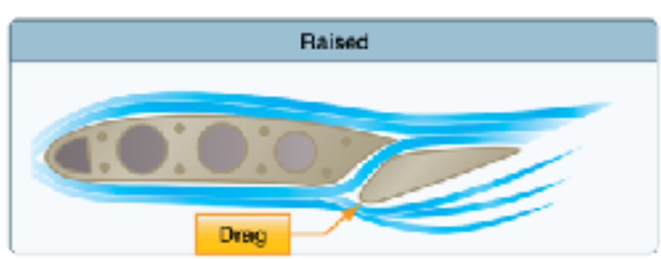


Figure 3 Frise Type Ailerons

2.2. Elevators and Stabilators **Give SBT example - taking off (reach climb attitude)/level off**

The entire horizontal stabilizer assembly includes a fixed airfoil and the pivotable elevator. The deflection of the elevator increases or decreases the camber, which alter the downward aerodynamic force produced, inducing a pitch change about the lateral axis. Due to the p-factor left turning tendency, an increase in pitch is usually accompanied by a yaw coupling to the left.

Figure 4 Elevator Control

The horizontal stabilizer can either be designed symmetric or with a slight camber to minimize the drag penalty from the needed downward aerodynamic force. Stabilator controlled aircraft rotate the entire horizontal stabilizer to alter the downward aerodynamic force and are mostly seen on PA-28s, PA-32s, PA-44s, Cessna Cardinals, and fighters (to minimize radar reflections from panel gaps and maximize agility).

Figure 5 Stabilators on Various Aircraft
Left – Piper PA-28
Center – Cessna 177 Cardinal (with slots to improve low speed handling)
Right – General Dynamics F-16

Some aircraft mount the horizontal stabilizer at the top of the vertical stabilizer, known as a T-tail configuration due to looking like the letter “T” from straight on. The horizontal stabilizer is removed from the propellor blast, allowing similar handling qualities across a range of airspeeds. Numerous business jet and transport category aircraft with engines mounted on the aft fuselage elect to utilize a T-tail to prevent hot exhaust gases from impinging on the stabilizer’s leading edge.

Figure 6 Dissimilar T-Tail Aircraft
Left – Embraer Phenom 300
Right – Piper PA-38 Tomahawk

2.3. Rudders Give SBT example - countering adverse yaw and taxiing

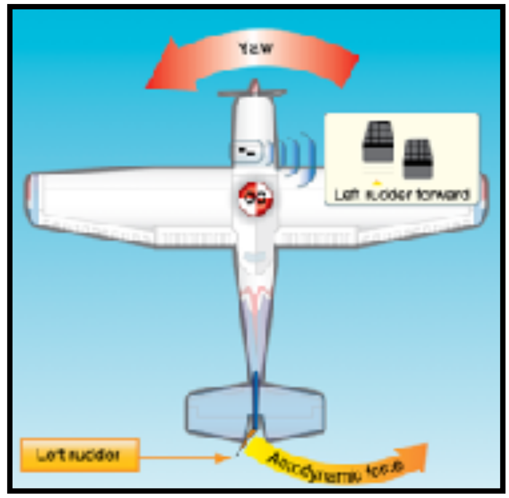


Figure 6 Rudder Effect

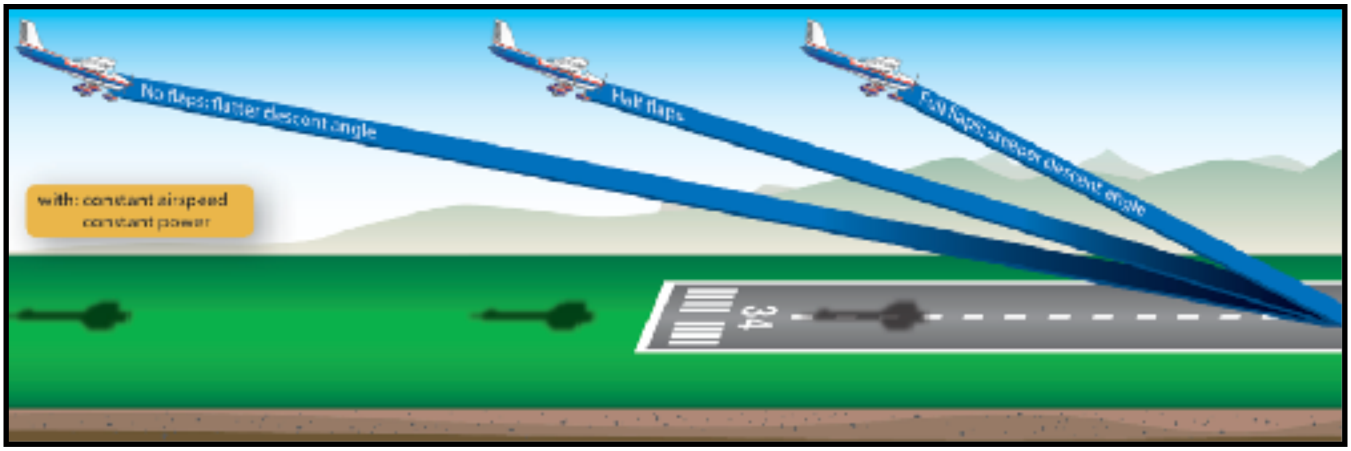
Rudders allow the aircraft to rotate about the vertical axis. Most rudders are mounted as the trailing edge of a symmetric vertical stabilizer. They are used for every maneuver although rarely exclusively, rather they help the aircraft combat the coupling as a result of the aforementioned tendencies.

If the rudder was actuated solely, the aircraft would not simply rotate about the vertical axis. The wing on the outside of the turn would move faster than the inner wing, producing more lift and introducing a roll about the longitudinal axis. The wing that produces more lift then also produces more drag (from induced drag), and induces an opposing yaw opposite to the initial yaw input. Another roll results and the cycle continues. This is known as Dutch Roll, and can be seen in this TU-154 in **this video** or **this video**.

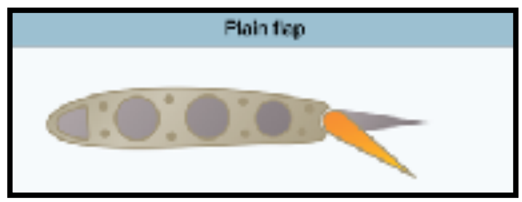
3. SECONDARY FLIGHT CONTROLS

3.1. Flaps

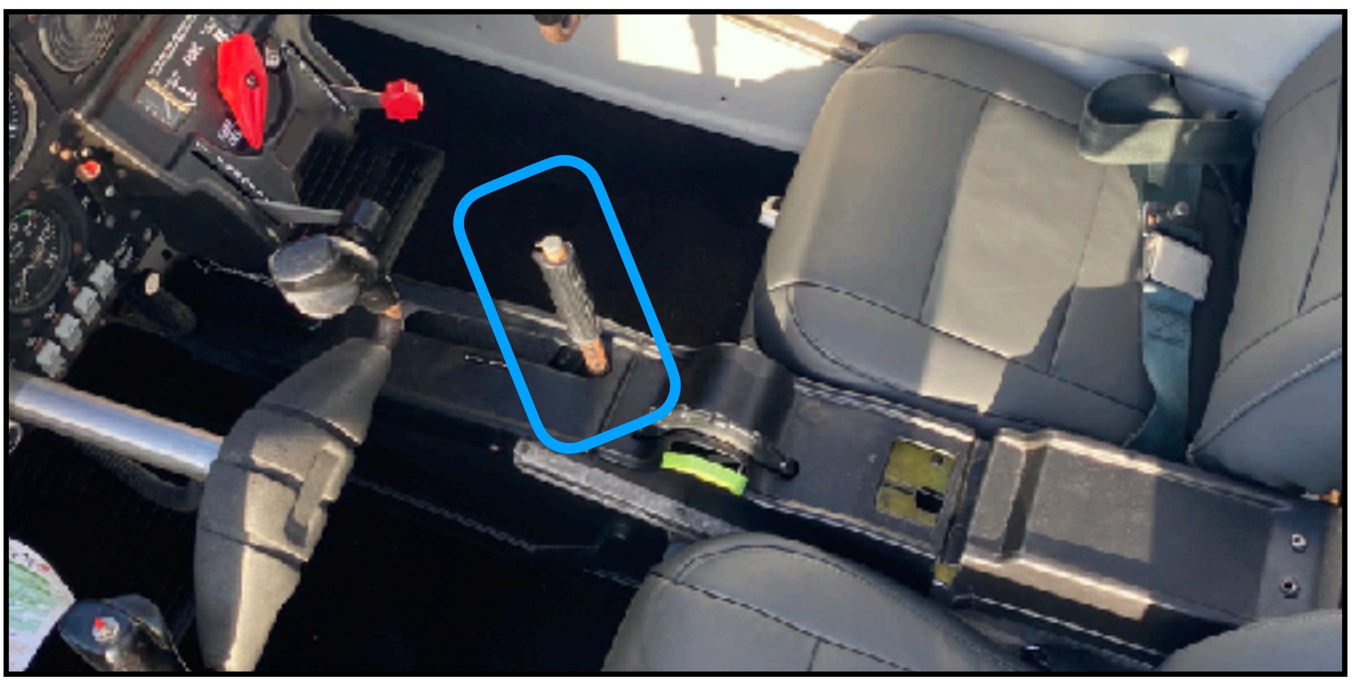
As discussed in Principles of Flight, flaps serve to increase the C_L of the wing, permitting enhanced low speed performance. More severe flap deflections can also increase drag significantly, aiding in slowing the aircraft down to permit steep approaches. Additional, due to the increase of C_L, stall speed decreases and minimum turn radius decreases. Numerous types of flaps exist and may be installed depending on the aircraft's mission.



Plain flaps are the simplest. They simply increase the effective camber of the airfoil, shifting the C_L curve upward (or sometimes upward and left). These flaps also move the center of pressure aft, resulting in a nose down pitching moment when deployed. Aircraft include the Piper PA-38 Tomahawk.



The Piper Tomahawk utilizes manual flap control. A flap handle, located within the center console, allows the pilot to set the flaps at one of three positions - 0°, 21°, and 34°.



Old WWII-era aircraft utilized split flaps, where only the lower surface would deploy. Split flaps generate higher CL for a given flap size and deflection at an equal or lower CD, according to three NACA reports (1, 2, 3). However, this conflicts with the FAA-H-8083-25C Pilots Handbook of Aeronautical Knowledge.

Slotted flap have made their way mainstream on all types of aircraft. From the Pilots Handbook of Aeronautical Knowledge,

> On small aircraft, the hinge is located below the lower surface of the flap, and when the flap is lowered, a duct forms between the flap well in the wing and the leading edge of the flap. When the slotted flap is lowered, high energy air from the lower surface is ducted to the flap's upper surface. The high energy air from the slot accelerates the upper surface boundary layer and delays airflow separation, providing a higher CL. Thus, the slotted flap produces much greater increases in maximum coefficient of lift (CL-MAX) than the plain or split flap. While there are many types of slotted flaps, large aircraft often have double- and even triple-slotted flaps. These allow the maximum increase in drag without the airflow over the flaps separating and destroying the lift they produce.

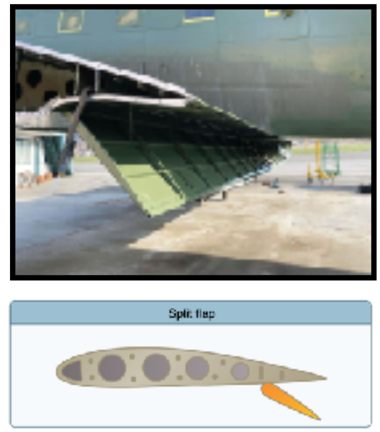


Figure 7 Split Flap
DC-3/C-47 with split flap under inboard wing and fuselage

The fowler flap is simply a variant of the slotted flap where the flap slides aft and downward, like on this Cessna 206.

Figure 8 Fowler Flaps on Cessna 206
Although blocking the rear cargo door

Slotted Fowler Flaps are commonly seen on large transport category aircraft, such as the Boeing 747 with triple slotted flaps.

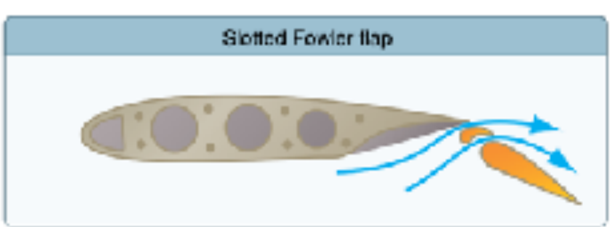


Figure 9 Slotted Fowler Flaps on Boeing 747

Mixed Flap

If an aircraft has a combination of these flap arrangements, it is known as a mixed flap. The diamond series aircraft has a split flap inboard to allow passengers to board by walking on the wing, but transition to plain flaps for the rest, as seen in figure x.

Figure 10 Mixed Flap on Diamond DA-42 Twin Star

Not all aircraft have this conventional layout. Design constraints, desired performance, or weight savings can motivate manufactures to merge flight control surfaces together, resulting in three common hybrid controls: elevons (elevator and aileron), ruddervators (rudder and elevator), spoilerons (spoilers and ailerons), and flaperons (flaps and ailerons).

3.2. Trim

Imperfect control rigging, varying flight conditions, and asymmetric loading may require a constant control input to remain in the desired flight attitude. Trim systems allow pilots to apply a constant input on some or all surfaces. Remember, trim is an *airspeed* control, so pitch, airspeed, power, trim.

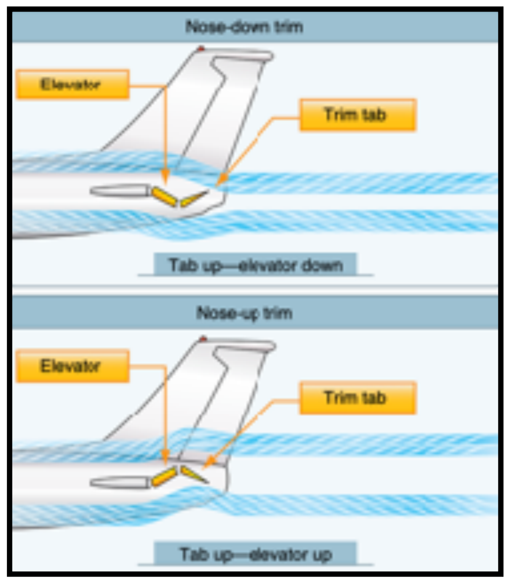
Trim Tabs are the simplest trim solution, consisting of a small extension or cutout in the control surface adjustable either in flight or on-ground. Rudder trims are typically only ground adjustable on small aircraft, although some cross-country focused aircraft will have in-flight rudder adjustable trim tabs. Elevator trim tabs are typically in-flight adjustable.

The tab direction moves opposite to the desired trim direction, since the tab applies a force to the control surface, not the aircraft. For example, the trim on the red aircraft in figure 15 would apply a force to deflect the rudder to the right.

Figure 11 Trim Tabs
Left – Cessna 172 Skyhawk with ground adjustable trim tab on rudder and in-flight adjustable trim tab on elevator
Right – Close view of ground adjustable trim tab

Balance Tabs

Balance tabs function similar to in-flight adjustable trim tabs, except they also deflect depending as the control surface deflects. As the pilot moves the primary control surface in one direction, the balance tab automatically moves in the opposite direction. This allows for decreased needed force of control input. These tabs are not always adjustable independently, meaning there is no cockpit control.

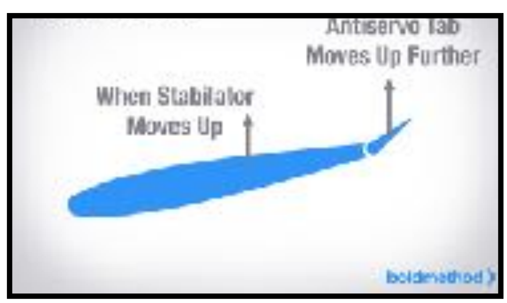


Servo Tabs

In a servo tab equipped aircraft, the pilot controls the position of the trim tab via the the flight controls. The force of the trim tab then moves that primary control. This decreases the force needed to deflect the flight control, which is greater as aircraft size increases.

Antiservo Tabs

Anti servo tabs are identical to balance tabs, except they move in the same direction as the control surface. These decrease the sensitivity on the stabilizer, preventing the pilot from over-controlling the aircraft.

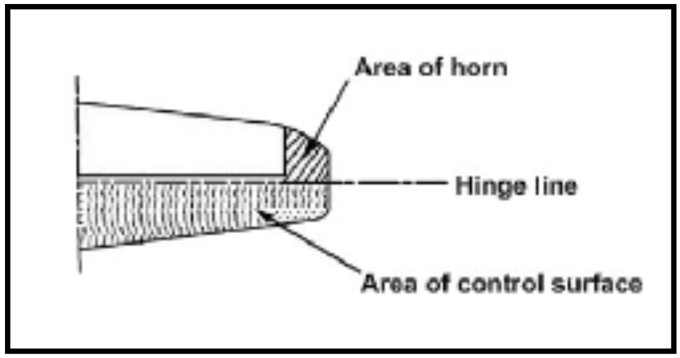


Piper PA-38 Tomahawk Trim System

The Tomahawk does not utilize any of these systems. Rather, a center located trim wheel pulls on bungees which apply a force to the control surface. There is no elevator trim tab. There is, however traditional rudder trim tab.

Horn Balance

Some control surfaces include area forward of the hinge, known as a **horn balance**. This serves two purposes: weights can be placed to balance the control surface relative to the hinge, and the horn acts as a "power steering", helping alleviate control loads with no additional moving components.



4. HYBRID FLIGHT CONTROLS

4.1. Elevons

On delta-wing and flying wing aircraft, there isn't traditionally a dedicated horizontal stabilizer. Thus, since the trailing edge of the main wing is so far aft, the ailerons could also function as elevators if they move in the same direction. This arrangement was common on notable aircraft such as the Concorde, North American XB-70 Valkyrie, and Northrop Grumman B-2 Spirit.

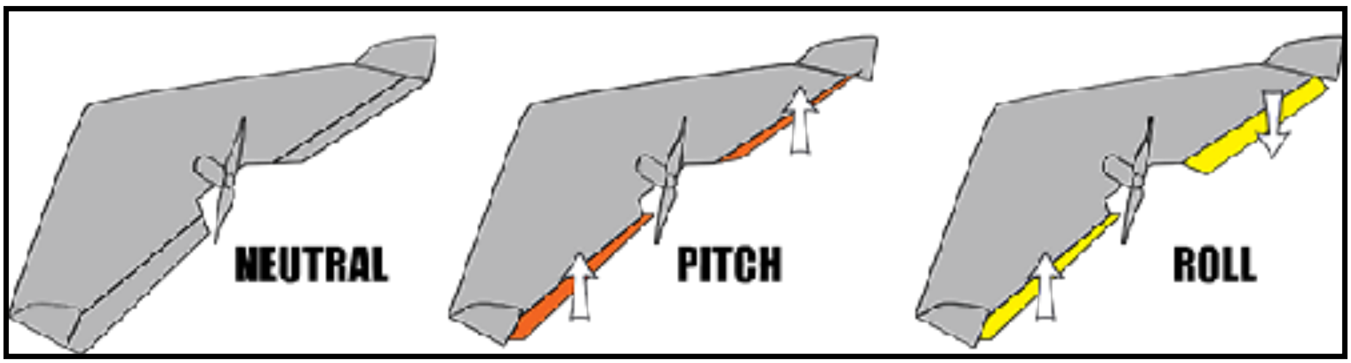


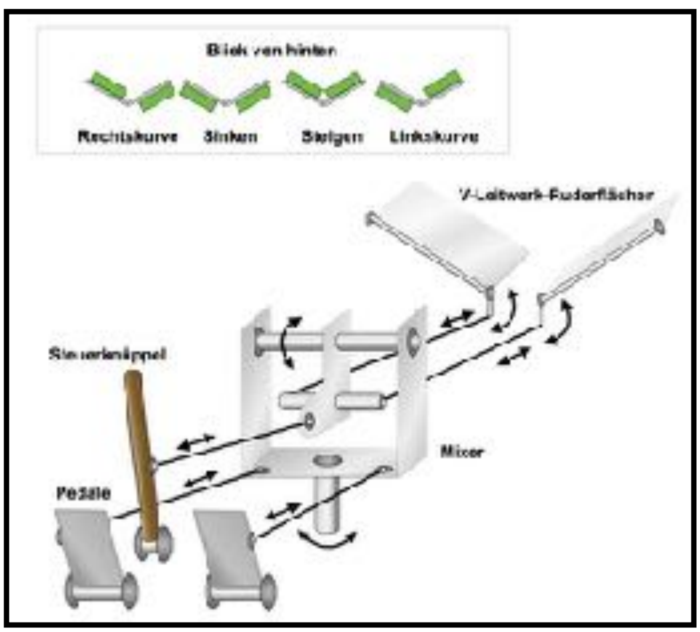
Figure 7 Elevon Surfaces on Trailing Edge
Left – North American XB-70 Valkyrie (all six control surfaces)
Right – Northrop Grumman B-2 (elevons locating on surfaces 1, 2, and 3 from center)

4.2. Ruddervators

V-Tail aircraft find benefit in all facets of aviation, from general aviation, commercial, and military. Elevator and rudder control is combined into two control surfaces, a significant drag and weight decrease from a standard tail, useful in all applications. Military aircraft benefit from a non-orthogonal surface, which assists in minimizing radar reflectivity. Commercial aircraft can mount a single engine above the fuselage without hot exhaust gases impinging on the vertical stabilizer.

However, complexity is increased as the system requires a mixer (figure 9) to output a combination of the differential rudder control and uniform elevator control. Many GA aircraft utilize a mechanical mixer, although commercial and military application may employ a fly-by-wire system. Total control authority is decreased as a result of this control mixing.

Figure 8 V-Tail Aircraft
Left – Northrop YF-23 Black Widow II V Tail
Right – Cirrus SF50 Vision Jet



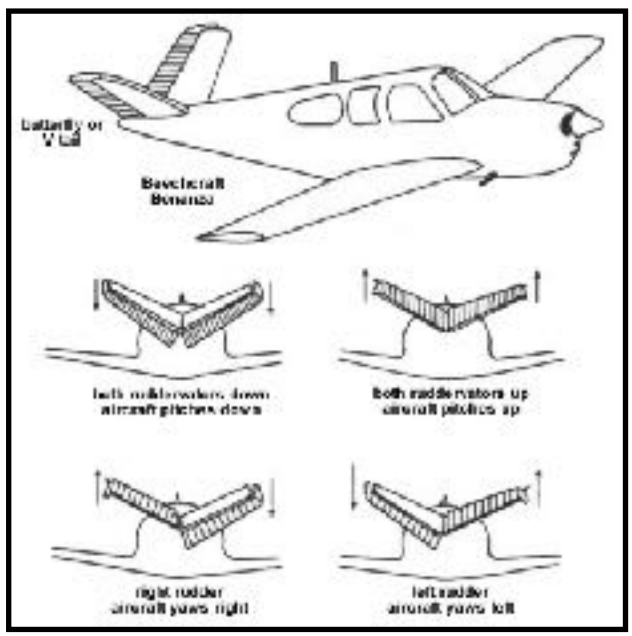


Figure 9 Four Mixable Control Modes

4.3. Flaperons

For some manufactures, low-speed performance is the preeminent goal. As discussed in Airplane Aerodynamics and Performance, flaps significantly increase the airfoil's lift coefficient, allowing stable flight at slower airspeeds. If we increase the flap size to the entire width of the airfoil, we would then need a method to achieve roll control about the longitudinal axis. Some aircraft have flaperons, or full length ailerons that can deploy simultaneously as well to function as flaps.

A mixer similar to that in a V-tail is needed to control both flap deployment and aileron actuation. Flaperons also find use in transport category aircraft, as their shorter moment arm can be more practical for roll control at high airspeeds.

Figure 11 Boeing 787 Flaperon Deflecting
Flaperon disconnects from hydraulic power during TO/GA power and falls due to gravity, then deflects upward from aerodynamic forces, then reconnects at sufficient speed [**source**] [**video**]

4.4. Spoilerons

On larger aircraft at high speeds, aileron usage may induce significant wing torsional forces rather than roll moments (reversal of $C_{l_{\delta_a}}$). Additionally, removing ailerons completely frees up space for full span flaps that can remain fully effective due to not needing to be mixed with aileron controls.

Spoilerons use the spoilers to decrease the lift on one side of the aircraft to induce a roll. Because they do not add lift, there are no adverse yaw effects, and since they also produce drag they may even introduce proverse yaw which helps the aircraft remain coordinated in a turn. Aircraft have even completely removed ailerons in favor of spoilers, such as the Mitsubishi MU-2 and Boeing B-52G/H/J Stratofortress.

Figure 12 Spoilerons
Left – Mitsubishi MU-2 with flaps fully deployed and left wind spoiler up
Right – B-52H with flaps deployed with no visible ailerons. Spoilers visible forward of outboard flap

By definition, spoilers only deflect upward. However, some aircraft have spoilers mechanically linked to the ailerons, which require them to deflect into the wing during aileron down inputs. This serves no effect. From the Daher TBM-850 POH:

> Aileron displacement is combined with that of spoilers, located at upper surface of each wing forward of flaps.
>
> The spoiler rises from wing upper surface profile, when the aileron is deflected upwards and remains in wing profile, when the aileron is deflected downwards.

Figure 13 Linked Aileron and Spoiler Deflection [**video**]
Left – Down
Right – Up

On most traditional GA aircraft flight control actuation is achieved via a combination of pushrods, cables, and pulleys, regardless of the specific flight control configuration.

However, the Piper Tomahawk employs traditional aileron, elevator, and rudder primary flight control surfaces aided by flaps and trim. A chain (similar to a bike) connects the two ailerons to a central torque tube, which converts rotational motion into translational cable movement leading into the wings. Elevator control is achieved by tilting the entire control column, which pulls on cables which run to the tail. Rudder control is similar via actuation of the rudder pedals.

The center-mounted flap handle rotates a torque tube, which actuates push rods to deploy both flaps equally. Two detents, seen in figure 1.2 part 21, lock the flaps up at 21° or 34°. The flaps do not lock in the down direction.

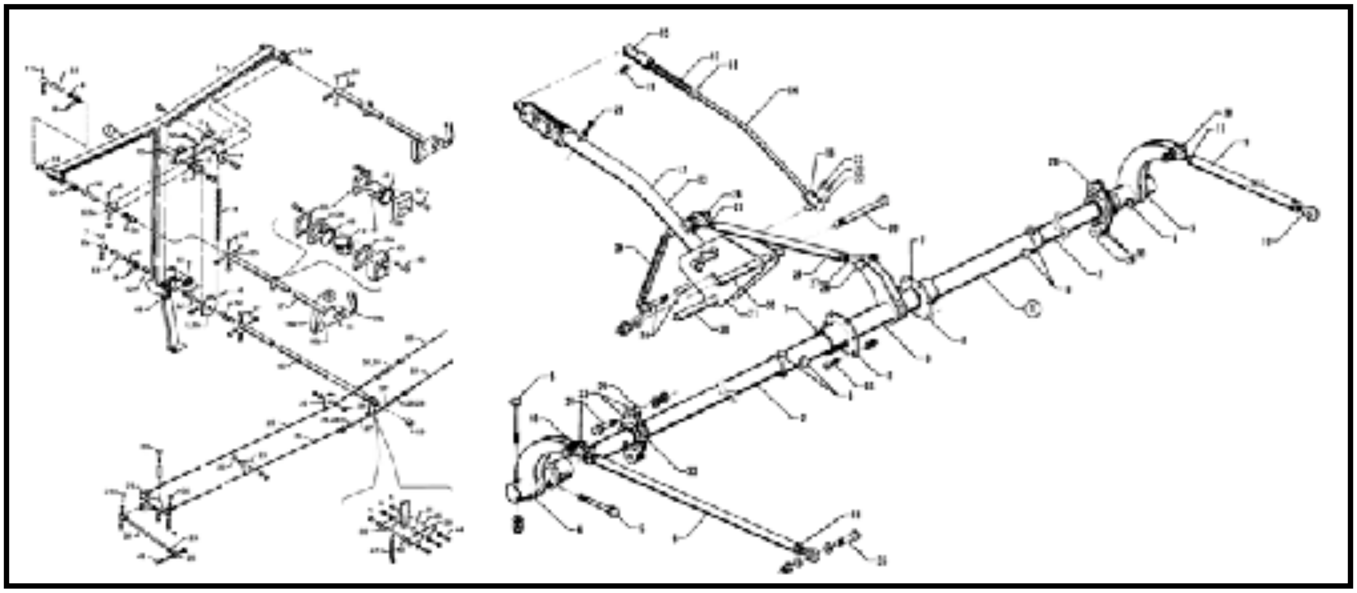


Figure 18 Ailerons (left) and Flaps (right)

Canard

Unlike a traditional configuration where the wing's center of lift and elevator's downward aerodynamic force are located behind the center of gravity, canard equipped aircraft have two lift surfaces for improved aerodynamic efficiency. Since lift is on either side of the center of gravity, there is no downforce that must be accounted for by the wing.

Figure 14 Canard Equipped Aircraft
Left – Rutan Factory Long-EZ
Center – Beechcraft Starship
Right – Scaled Composites Proteus

Canard aircraft require a few unique design considerations. The forward wing must stall first so that the aircraft has a natural pitch-down tendency. Otherwise, stalls would be unrecoverable. The forward wing usually requires the engine to be placed in the back, resulting in a pusher configuration. Since the elevator is mounted on the forward wing (it is further form the center of gravity), elevator movement is reversed from what would be seen on a a traditional configuration.